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Some Recent Nuclear Cross Section Measurements at ORNL

February 1, 1965 - August 31, 1965

P. H. Stelson

Abstract

This memo reviews some of the recent nuclear cross section activities at ORNL for the period February 1, 1965 through August 31, 1965.

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1. Neutron Scattering Cross Sections for Silicon Determined by Time-of-Flight Technique -- J. A. Biggerstaff, J. K. Dickens, M. V. Harlow, Jr., W. E. Kinney, and F. G. Perey

Absolute differential cross sections for elastic scattering and inelastic scattering (Q = -1.78 MeV) of 5.03 and 5.6 MeV neutrons from natural silicon have been measured at laboratory angles of 21, 31, 41, 56, 72, 92, 112, and 132°. Bursts of deuterons, 2 nsec wide at half maximum, from the ORNL 3 MV Van de Graaff accelerator bombarded a double-foil deuterium gas target, thereby producing, by the $D(d,n)^3He$ reaction, bursts of monoenergetic neutrons. Samples of silicon and carbon, the latter used as a standard, were placed at zero degrees and at distances of from 7 to 12 cm from the target. Both samples were right circular cylinders approximately 1/3 mean free path thick to 5 MeV neutrons.

Scattered neutrons were detected by a scintillation detector, which utilized neutron-gamma discrimination, located 3 m from the sample. A long counter, placed at 65°, monitored the neutron intensity from the target. Time-of-flight spectra of the scattered neutrons were taken with a 4096-channel, two-dimensional, pulse-height analyzer in which input pulses were sorted according to their pulse height and their time-of-flight amplitude. Output paper tapes from this analyzer were then fed into a CDC 160A computer, where they were corrected for background effects and for time-walk perturbations (W. E. Kinney, Data Reduction Programs for the CDC 160A Computer, ORNL-TM-1208 (in preparation)).

Absolute differential cross sections for silicon were obtained by normalizing relative cross sections of silicon to those measured for the carbon sample at each angle. Although multiple scattering corrections to the data are not yet completed, the uncorrected 5.03 MeV cross sections are in good qualitative agreement with 4.8 MeV data taken elsewhere (M. D. Goldberg et al., Angular Distributions in Neutron-Induced Reactions, BNL-400, 2d ed., Vol. I, p. 14-28-1 (October 1962)). Final corrected results will partially satisfy a Priority 1 request for silicon cross-section data (A. B. Smith, compiler, Compilation of Requests for Nuclear Cross Section Measurements, WASH-1047 (EANDC (US)-53"U"), p. 18 (February 1964)).

2. Neutron Scattering from Nitrogen -- J. L. Fowler and C. H. Johnson

We have used apparatus designed to determine differential scattering of neutrons from liquid oxygen (J. L. Fowler and C. H. Johnson, Bull. Am. Phys. Soc. 10, 261 (1965)) to measure the differential scattering of neutrons from liquid nitrogen at several resonant and non-resonant energies between 1.5 and 2.3 MeV. At the 1.595 and 2.25 MeV resonances we confirm angular distributions deduced from nitrogen recoils which we had reported earlier (J. L. Fowler and C. H. Johnson, Phys. Rev. 98, 728 (1955)). Being a more direct measurement of differential scattering than that reported previously, our present results are more reliable than the earlier ones. At non-resonant energies of 1.68 and 2.00 MeV, the angular distributions are not isotropic, indicating the presence of partial waves of higher angular momentum than s-waves.

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3. Intermediate States as Observed by Differential Scattering of Neutrons by Doubly Closed Shell Nuclei -- C. H. Johnson and J. L. Fowler

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 1965.

> Since relatively simple intermediate states are expected to appear around closed shells, we have observed neutron scattering from the doubly closed shell nuclei ^{16}O and ^{208}Pb. We measured total cross sections by transmission and differential elastic cross sections by scattering neutrons from a sample centered in a shielded chamber. For ^{16}O we made a phase shift analysis for neutron energies from 2.25 to 4.2 MeV. Broad resonances shown by this analysis include a $d_{3/2}$ resonance at 3.40 MeV and $p_{3/2}$ at 3.75 MeV. The widths, ~ 500 keV, are about 1/2 of the single particle limit for the first case and 1/5 for the latter. Good resolution total cross section measurements confirm the J = 5/2 assignment for the 3.77 MeV resonance, and the phase shift analysis assigns odd parity. For ^{208}Pb we measured the differential cross section near most of the prominent isolated resonances observed in the total cross section for 0.7 to 1.8 MeV neutrons. The analysis determined the parity for 20 resonances whose J values were assigned from the total cross section. Several of the resonances, or groups of resonances, are likely candidates for states of intermediate structure such as two-particle one-hole states.

4. Simultaneous Measurements of the Neutron Fission and Capture Cross Sections of ^{235}U -- L. W. Weston, R. Gwin, J. E. Russell (deceased), and R. W. Hockenbury (RPI, Troy, N.Y.)

The program for measuring the ratio of the capture and fission cross sections (α) of ^{235}U has been continued with measurements conducted at the Rensselaer Polytechnic Institute Electron Linear Accelerator in the energy range 0.4 eV to 2 keV. The technique was the same as that used for earlier measurements (L. W. Weston, G. deSaussure, and R. Gwin, Nucl. Sci. Eng. 20, 80 (1964)) except that a ^{10}B-NaI detector was used to measure the neutron flux through the ^{235}U fission chamber. The important feature of these measurements is that the capture and fission cross sections were determined simultaneously under identical conditions with the same sample, thus eliminating many relative errors between the capture and fission cross sections such as slight errors in neutron energy, neutron flux, neutron scattering effects, etc.

The analysis of the measurements is incomplete, but a typical uncorrected time-of-flight spectrum is shown in Fig. 1 where the scale at the bottom represents a neutron energy from 10 keV at the left to 0.2 eV at the right. The sharp breaks in the spectrum were caused by the computer changing the effective time-of-flight channel widths.

The measurements will be analyzed to obtain resonance integrals over various neutron energy ranges, as well as the differential cross

sections. Resonance integrals are of value in computing gross characteristics of reactors, whereas differential cross-section data are used to calculate Doppler coefficients and flux depressions.

A feasibility study on the measurement of the capture and fission cross sections of ^{239}Pu was also performed with the RPI Linac. The pulse-height spectrum method of discriminating capture from fission was used (R. Gwin et al., Neutron Phys. Div. Ann. Prog. Report Aug. 1, 1963, ORNL-3499, Vol. I, p. 15). Analysis of this study will be continued.

5. Method for Obtaining Bursts of Polarized Neutrons with Energies 10-700 keV -- J. W. T. Dabbs and J. A. Harvey

The following is an abstract of a paper submitted to the International Conference on Polarization Phenomena of Nucleons, Karlsruhe, Germany, September 6-11, 1965.

> A pulsed electron linear accelerator of ~ 100 MeV with a W or U target provides an intense source of neutrons with a strong peak in intensity at ~ 1.2 MeV. This peak fits surprisingly well with peaks in both cross section and polarization associated with the well known p-wave resonance in He. A single scattering through 90° ± 15° (Lab) gives a calculated average neutron polarization greater than 50 percent; a detailed Monte Carlo polarization calculation shows that these neutrons (median energy 700 keV) can be moderated by a graphite block to low energies without appreciable loss of polarization. A severe loss of intensity at lower energies is caused by the high escape probability from practical (10 cm cube) graphite moderators; nevertheless the intensity appears usable for energies greater than ~ 10 keV.

6. High Resolution Measurements of Gamma Rays from Thermal and Resonance Neutron Capture -- G. G. Slaughter, J. A. Harvey, and M. J. Martin

High resolution measurements of the gamma rays from thermal neutron capture in the ten isotopes of Sn, the five isotopes of Zr and four isotopes of W have been made using lithium-drifted germanium detectors. The lithium-drifted germanium detectors had sensitive volumes of 1.9 and 6 cm^2 respectively and had energy resolutions ~ 10 keV at 6 MeV. Measurements have been made also of the gamma rays following the capture of resonance energy neutrons in the isotopes of Sn and Zr. In general, resonance capture in the Sn isotopes results in gamma spectra containing only a few strong lines, such as the transitions to the low-lying $s_{1/2}$ and $d_{3/2}$ states by capture in the even-A isotopes. In a few cases, specific gamma rays were observed with resonance neutrons which were not found with thermal neutrons. (Preliminary results for thermal and resonance capture by ^{117}Sn, ^{118}Sn and ^{120}Sn were given at the Antwerp meeting, July 19-23, 1965.) The results from all the nuclides are being compared to level diagrams obtained from (d,p) reactions and radioactive decay data.

7. High Resolution Measurements of Gamma Rays from Thermal and Resonance Neutron Capture in ^{117}Sn, ^{118}Sn and ^{120}Sn -- J. A. Harvey and G. G. Slaughter

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

High resolution measurements of the gamma ray spectra from thermal and resonance neutron capture in ^{117}Sn, ^{118}Sn and ^{120}Sn have been made using a 1.9 cm^3 lithium-drifted Ge detector (Ge crystal furnished by R. J. Fox, ORNL). High energy transitions to the ground state (E_γ = 9315 ± 10 keV) and to excited states of ^{118}Sn at 1225, 1675, 2040, 2480 keV and higher were observed from both thermal and resonance capture in ^{117}Sn, but the transition to the state at 1750 keV was observed only from resonance capture and the transition to the state at 2020 keV only from thermal capture. Low energy gamma rays with energies 1224, 418, 531 and 812 keV from thermal capture can be fitted into the level diagram. Resonance neutron capture in ^{118}Sn emits strong gamma rays (~ 6% and ~ 15%) to the ground state (E_γ = 6485 ± 10 keV) and to the excited state at 24 keV; whereas thermal capture gives a weak transition (~ 0.6%) to this 24 keV state, and the transition to the ground state is not observed (< 0.1%). Fifteen other gamma rays were observed from thermal capture. Low energy gamma rays with energies 763, 898, 921, 1067 and 1295 keV (all ± 2 keV) observed from thermal capture can be fitted into the level diagram with excited states at 24, 763, 921, 1091 and 1319 keV. Resonance capture in ^{120}Sn produces strong transitions (~ 5% and ~ 20%) to the ground state (E_γ = 6164 ± 10 keV) and an excited state at 60 keV, whereas the transitions to these two states are weak (~ 0.4% and ~ 0.6%) from thermal capture. More than 20 other gamma rays were observed from thermal capture.

8. Strong p-Wave Neutron Resonances in ^{120}Sn, ^{118}Sn and ^{124}Sn -- J. A. Harvey and Toyojiro Fuketa (Permanent address: JAERI, Tokai, Japan)

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

Neutron transmission measurements have been made with the ORNL fast chopper time-of-flight spectrometer on 10 cm thick metal samples of ^{120}Sn (98%) and ^{118}Sn (97%). Measurements were made at the 45 meter flight station with a resolution of 60 nanoseconds/meter and at the 180 meter flight station with a resolution of 15 nanoseconds/meter. The resonances in ^{120}Sn at 427 and 1720 eV with ~ 20% and ~ 70% scattering respectively are p-wave resonances, and the resonance at 922 eV with ~ 50% scattering is an s-wave resonance. The large resonance in ^{118}Sn at 359, 770, 1580, 2960, 3450 and 7400 eV are definitely s-wave resonances; while the resonance at 45.8 eV

with only ~ 0.6% scattering is probably a p-wave resonance. From the analysis of transmission measurements with a 2.5 cm thick sample of ^{124}Sn (93%), the 62.0 eV resonance with 10% scattering is definitely a p-wave resonance. This resonance is ~ 100 times stronger than expected for an average p-wave resonance for this nuclide and ~ 1/100 of the Wigner limit. This strong p-wave resonance has a reduced neutron width which is comparable to those computed by Shakin (C. Shakin, Annals of Physics 22, 373 (1963) for 3 quasi-particle s-wave states, and hence is suggestive of a p-wave "doorway" state. The p-wave resonance at 427 eV and 1720 eV in ^{120}Sn and 45.8 eV in ^{118}Sn are ~ 20 times stronger than expected for average p-wave resonances for these nuclides.

9. Level Spacing and s-Wave Neutron Strength Function of the Odd-Odd Nuclide ^{138}La -- J. A. Harvey and G. G. Slaughter

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

Neutron transmission measurements have been made with the ORNL fast chopper time-of-flight spectrometer upon a 1.17 gram sample of La_2O_3 enriched to 7.0% in ^{138}La and a sample of natural lanthanum. The measurements were made at the 45 meter flight station from 0.2 to ~ 2 keV with a resolution from 1 to 2% in energy below 50 eV and 60 nanoseconds/m above 50 eV. The transmission measurements were analyzed using the area analysis program. Neutron widths were obtained for the 8 resonances assigned to ^{138}La at 3.08, 21.1, 66.7, 89, 130, 237, 260 and 304 eV. From the parameters of the 5 resonances observed up to 160 eV and a 40% correction for "missed" resonances, a value of 46 ± 15 eV was obtained for the average level spacing per spin state. A value of $(0,8 \pm 0.5) \times 10^{-4}$ was obtained for the s-wave strength function from the parameters of the 7 resonances up to 280 eV and a 16% correction for "missed" resonances. The radiation width of the 3.08 eV resonance was determined to be 0.11 ± 0.01 eV from shape analysis of transmission data obtained using a natural lanthanum sample.

10. Parameters of Neutron Resonances in ^{180}W -- Hans Jung (visitor from Kiel University, Germany)

Transmission measurements have been made with the ORR fast chopper time-of-flight spectrometer upon an 8-gram sample of ^{180}W enriched to 6.93%. Measurements were made using BF_3 proportional counters at the 45-meter flight station with a resolution of 1 to 2% from 0.1 to 100 eV and 50 nanoseconds/meter from 100 eV to 400 eV. The sample was packed to cover 4 slits resulting in a sample thickness of 0.0194 atoms of W/barn. The transmission data have been analyzed by the area analysis program assuming a radiation width of 0.060 eV. Parameters have been obtained for 5 resonances in ^{180}W and are listed below.

E_o (eV)	Γ_n (10^{-3} eV)	Γ_n^o (10^{-3} eV)
15.9 ± 0.1	12.5 ± 1.5	3.0
49.3 ± 0.1	6.2 ± 0.7	0.88
62.7 ± 0.2	1.4 ± 0.2	0.18
75.2 ± 0.2	35 ± 2	4.0
87.4 ± 0.3	7.3 ± 0.5	0.78

11. Neutron Capture Cross Sections from 5 to 100 keV -- R. L. Macklin and J. H. Gibbons

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

Recent results and advances in technique for 5-100 keV neutron capture cross section measurements are reviewed. A major summary of cross sections averaged over various Maxwellian temperatures have been presented in the Reviews of Modern Physics. Included in this document are previously unpublished ORNL cross sections versus energy for several of the lighter (A < 70) elements.

12. Energy Dependence of the $^{10}B(n,\alpha)/^{10}B(n,\alpha\gamma)$ Ratio -- R. L. Macklin and J. H. Gibbons

The following is an abstract of a paper submitted for publication in the Physical Review.

The alpha particle and lithium ion recoils from this reaction were observed in coincidence in face-to-face surface barrier silicon detectors, using 0.1 atmosphere of $^{10}B_2H_6$ as sample. Neutrons were provided by the ORNL 3-MV pulsed Van de Graaff using the $^7Li(p,n)$ reaction. Cross section ratios, $(n,\alpha_o)/(n,\alpha_1)$, of 0.084 ± .005 (160 keV), 0.077 ± .004 (110 keV), 0.072 ± .003 (30 keV) and 0.067 ± .002 (thermal neutrons) were found. These results indicate a small monotonic variation in the ratio in good agreement with earlier measurements at higher energies.

13. Search for γ Rays from $^{10}B(n,\gamma)$ near 230 keV -- J. A. Biggerstaff

Recent investigations of the reaction ^{10}B have given evidence that the reaction (^{10}B + n) is not well understood, particularly for $100 < E_n$ (keV) $\lesssim 400$. The Argonne work contains new measurements in this

energy range of σ_t and σ_a. The total cross section shows a peak near 230 keV. If one subtracts the cross section for the reaction (n,α plus n,$\alpha\gamma$), as obtained by various workers at Rice, from the Argonne values of σ_{abs} the residual curve shows a distinct peak at 230 keV (peak residual cross section is as large as 400 mb) with a finite contribution as low as 100 keV. If such a cross section exists it must be due to other channels such as (n,t) or perhaps even (n,γ). The chance for significant γ-ray emission in the presence of particle emission should be low but nevertheless worth examining.

We used a 9 x 12" NaI crystal and the ORNL 3 MV pulsed Van de Graaff with an approximately 20 keV thick target to look for γ rays ($E_\gamma > 0.5$ MeV) from this process. The result was negative, that is, no γ's were observed. The upper limit on the peak cross section due to (n,γ) is estimated to be 10 mb.

14. On the Absolute Value and Energy Dependence of the ^{3}He(n,p)T Reaction -- R. L. Macklin and J. H. Gibbons

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

> The absolute total yield from T(p,n)^{3}He has been carefully measured from threshold up to $E_p = 1.4$ MeV. The absolute cross section for ^{3}He(n,p)T was obtained by reciprocity over the energy interval corresponding to $5 < E_n$ (keV) < 300. The results indicate that the cross section becomes non- 1/v for $E_n \gtrsim 5$ keV. This departure from 1/v may be accounted for by assuming the existence of an excited state in ^{4}He near 20.1 MeV or perhaps by a final state (p-T) interaction.

15. A Study of the Resonances in Neutron Bombardment of ^{206}Pb and ^{207}Pb -- J. R. Bird (visiting scientist from AERE, Harwell, England), J. A. Biggerstaff, J. H. Gibbons, W. M. Good, and R. L. Macklin

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

> In light nuclei and in the neighborhood of closed shells, level spacings are of the order of a kilovolt or more. For such nuclei the pulsed Van de Graaff is a useful instrument for neutron investigations. In transmission, small samples can be studied with less than 2% energy resolution. By means of a three parameter analyzer capture gamma-ray spectra versus neutron energy have been obtained. The nuclei ^{206}Pb and ^{207}Pb have been studied and information has been obtained on E_o, Γ_n, Γ_γ, $\Gamma_{\gamma i}$. The result of the investigation has been to locate new bound and unbound states in ^{207}Pb, locate new unbound states in ^{208}Pb, establish the predominantly

p-wave character of the states in ^{207}Pb, ^{208}Pb near neutron dissociation, obtain information on electric and magnetic radiation reduced widths, and possibly also information on direct capture.

16. Neutron Resonance Structure and S-Wave Strength Function of the Even Isotopes of Zr -- J. A. Biggerstaff, W. M. Good, and H. Kim

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

Beginning at about mass 90, the s-wave strength function is anomalously small compared with the optical model prediction. First studies of the neutron resonances in the even isotopes of Zr (H. W. Newson, R. C. Block, P. F. Nichols, A. Taylor, A. K. Furr, and E. Merzbacher, Ann. Phys. 8, 218 (1959)) indicated a rise in the average cross section which was most consistent with a predominantly p-wave interaction. A small s-wave contribution did not seem surprising based upon the behavior of slightly heavier nuclei. However, subsequently more refined measurements (J. A. Biggerstaff, W. M. Good, and H. J. Kim, Bull. Am. Phys. Soc. 9, 167 (1964); S. S. Moskalev, H. V. Muradian, and Yu. V. Adamchuk, Nucl. Phys. 53, 667 (1964)) have indicated that the resonances at least to an energy of about 25 keV are s-wave with a strength function of about 1×10^{-4}. Data taken up to 60 keV now shows an average cross section which rises more rapidly than $\sqrt{E}$, contributed by resonances not sufficiently well resolved to permit distinguishing those of s-wave character. Unless the p-wave strength function can attain values of 30×10^{-4}, these results indicate an s-wave strength function below 25 keV $\approx 1 \times 10^{-4}$ which rises to 2×10^{-4} in the interval 40-60 keV.

17. Fast Neutron Capture Gamma-Ray Spectrum from $^{238}U(n,\gamma)^{239}U$ -- I. Bergqvist (Permanent address: Research Institute of National Defense, Stockholm, Sweden)

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

The gamma-ray spectrum from the capture of 30 keV neutrons in ^{238}U has been measured using a 9" x 12" NaI(Tl) spectrometer. Agreement with a statistically calculated spectrum is obtained. Evidence is given for a $K^{\pi} = 1/2^{+}$ band in ^{239}U at an excitation energy of 0.13 MeV, which can be identified as the [631] $1/2^{+}$ band. The number of levels below an excitation energy of about 1 MeV found in other experiments is compatible with the experimental gamma-ray spectrum.

18. Neutron Resonance Capture in 2s-1d Shell Nuclei -- I. Bergqvist (visiting scientist from Research Institute of National Defense, Stockholm, Sweden), J. A. Biggerstaff, J. H. Gibbons, and W. M. Good

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

A pulsed Van de Graaff has been used to measure gamma-ray spectra from neutron resonance capture in nuclei in the 2s-1d shell. A number of previously known neutron resonances in the keV region were studied. In many cases the emitted gamma-ray spectrum has a rather simple composition with transitions to low-lying levels with known spins and parities. It is found that M1 transitions from capturing states to low-lying levels of even parity are especially strong in odd Z nuclei and relatively weak in even Z nuclei. The results from thermal neutron capture experiments show the same systematic behavior. No strong M1 transitions from capturing states of negative parity have been identified. The existence of M1 giant resonance states close to the neutron binding energy in the odd Z nuclei might explain the enhancement of the M1 transitions found in these nuclei. A valid 2s-1d shell systematics could sometimes permit for such nuclei, gamma-ray spectral determination of both resonance spin and parity as examples will show.

19. S-Wave Neutron Strength Functions of Isotopes in the 3s Resonance Region $40 < A < 70$ -- R. Wagner (Present address: Physikalisches Institut der Universitat Basel, Switzerland), W. M. Good, and D. Paya (Present address: Commissariat A L'Energie Atomique, CEN, Saclay, France)

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

We have measured the total neutron cross section of ^{43}Ca, $^{47,49}Ti$, ^{53}Cr, ^{57}Fe, ^{61}Ni, and $^{63,65}Cu$ in the keV region using a pulsed beam time-of-flight technique. The energy resolution was 1 to 2% which was in general not sufficient to determine the angular momenta of the observed compound states. Seth's area analysis was used to determine the neutron widths of the observed resonances (K. K. Seth, Ann. Phys. 8, 223 (1959)). Except for these states for which angular momentum could be determined the statistical factor $g = (2J+1)/2(2I+1)$ was assumed to be 1/2. The s-wave strength functions obtained are in general agreement with the predictions of the optical models (B. Buck and F. Perey, Phys. Rev. Letters 8, 444 (1962)). A variation in the general appearance of the resonance structure is observed as the strength function maximum is crossed. ^{53}Cr has a large strength of about 14×10^{-4} if measurements extend up to only 20 keV; $(5.1 \pm 2.6) \times 10^{-4}$ is its strength, however, in energy range up to 40 keV, which would suggest the existence of a "local" strength.

20. Elastic and Inelastic Scattering of 5 MeV Neutrons from ^{27}Al, ^{56}Fe, ^{206}Pb, ^{207}Pb, and ^{209}Bi -- J. A. Biggerstaff, J. K. Dickens, M. V. Harlow, Jr., W. E. Kinney, F. G. Perey, and P. H. Stelson

Time-of-flight spectra for the scattering of 5 MeV neutrons from ^{27}Al, ^{56}Fe, ^{206}Pb, ^{207}Pb and ^{209}Bi have been obtained at 30, 40, 55, 60, 70, 80, 90, 100, 110 and 130°. The overall time resolution was ~ 2.5 nsec. γ-n discrimination was used. The Al, Fe and Bi samples are right circular cylinders, about 2 cm x 2 cm, of the naturally occurring element. The ^{206}Pb and ^{207}Pb samples are enriched to ~ 88% of the isotope for ^{206}Pb and to ~ 92% of the isotope for ^{207}Pb. The data at 60, 80, and 100° were obtained using a flight path of 5.36 m; the overall energy resolution for 5 MeV neutrons was ~ 150 keV. The remaining spectra were obtained using a flight path of 4 m. Differential cross sections for elastic scattering and for the inelastic excitation of individual levels in the struck nucleus are being extracted using the methods discussed above (in paragraph 1 of pg. 2).

21. $^{51}V(p,n)^{51}Cr$ Cross Section from Threshold to 2.25 MeV -- J. H. Gibbons and R. L. Macklin

The following is an abstract of an article submitted for publication in Nuclear Instruments and Methods.

> The absolute (p,n) total cross section for $^{51}V(p,n)$ has been measured from threshold to 2.25 MeV with an accuracy of 5%. The cross section measured with an ~ 15 keV thick target fluctuates appreciably despite the ~ 1 keV level spacing observed using a thin target. The small change of neutron energy with emission angle make this reaction a good 4π monoenergetic source.

22. N-D Scattering - Vector Polarization of Recoil Deuterons from a Polarized Neutron Beam -- H. B. Willard, S. T. Thornton (Oak Ridge Graduate Fellow from the University of Tennessee), and C. M. Jones

The following is an abstract of a paper presented at the International Conference on Polarization Phenomena of Nucleons, Karlsruhe, Germany, September 6-10, 1965.

> In N-D scattering two sets of scattering lengths are consistent with the low energy data: Set I, a_2 = 0.8 fm, a_4 = 6.4 fm; Set II, a_2 = 8.3 fm, a_4 = 2.6 fm where a_2 and a_4 are the doublet and quartet lengths, respectively. Although current theoretical calculations are converging on Set I, there does not appear to be any unambiguous experimental evidence for either choice. We have calculated the vector polarization of the scattered neutron and recoil deuteron for incident beams of completely polarized neutrons. Low energy (slow) neutrons produce scattered neutrons with polarizations of 66% (Set I) and 65% (Set II). On the other hand the vector polarizations of the recoil deuterons are +50% and -33%, respectively. At 350 keV neutron

energy the neutron polarizations are +51% (Set I) and +49% (Set II) while the deuteron vector polarizations are +38% (Set I) and -21% (Set II). Therefore a determination of the deuteron vector polarization in a triple scattering experiment provides a sensitive test for the proper scattering lengths. Detailed calculations of the pertinent parameters using the $^{7}Li(p,n)^{7}Be$ reaction as the polarized neutron source and possible deuteron vector polarization analyzers will be presented.

23. A Study of the $^{89}Y(p,n)^{89}Zr$ Reaction -- H. J. Kim and R. L. Robinson

The following is an abstract of a paper to be presented at the American Physical Society Meeting, Chicago, Illinois, October 28-30, 1965.

We have investigated 90° differential excitation functions and the angular distributions of the neutrons feeding the ground state and the first excited state of ^{89}Zr by the $^{89}Y(p,n)^{89}Zr$ reaction. The incident energy range and steps were so chosen that the 4.8 MeV isobaric analogue resonance was studied in detail. The neutrons from the above reaction were detected by a time-of-flight method in conjunction with the pulsed protons, which were obtained from the ORNL 5.5 MV accelerator. The excitation function of the neutrons feeding the first excited state of ^{89}Zr in the vicinity of the resonance behaves as if there is an interference effect between the resonance and off resonance reaction mechanisms. Analysis of the neutron angular distributions and of the excitation functions indicates that the statistical compound nucleus assumptions cannot be used to describe the off resonance reaction mechanism of the $^{89}Y(p,n)^{89}Zr$ reaction around the lowest lying isobaric analogue resonance of $p + {}^{89}Y$.

24. Fragment Energy Correlation Measurements for ^{252}Cf Spontaneous Fission and ^{235}U Thermal-Neutron Fission -- H. W. Schmitt, J. H. Neiler (Present address: Oak Ridge Technical Enterprises Corp. (ORTEC), Oak Ridge, Tennessee), and F. J. Walter (Present address: RIDL Division, Nuclear Chicago Corp., Oak Ridge, Tennessee)

The following is an abstract of a paper to be published in the Physical Review.

Fission fragment mass and energy distributions and mass-vs.-energy correlations have been obtained for ^{252}Cf spontaneous fission and ^{235}U thermal-neutron-induced fission. Silicon surface barrier detectors were used in energy correlation measurements; absolute fragment energies were obtained by means of the mass-dependent energy calibration developed recently at this Laboratory. Average total fragment kinetic energies before neutron emission are found to be 186.5 ± 1.2 MeV for ^{252}Cf and 171.9 ± 1.4 MeV for ^{235}U. Detailed experimental results are given and compared with those of other experiments. Observed fine structure in the fragment mass distribution and in the average total fragment kinetic energy as a function of mass is correlated with the energetically preferred even-even nucleon

configurations in the fragments. New determinations of the root-mean-square width of the total kinetic energy distribution as a function of mass show structure which is also correlated with the energetically preferred even-even fragment configurations. Fission neutron and gamma-ray data of other experiments are used with the new fragment kinetic energies presented here to examine the total energy balance for fission for the two cases studied.

25. Evaluation of Semiconductor Detectors for Fission Fragment Energy Measurements -- H. W. Schmitt and Frances Pleasonton

The following is an abstract of a paper submitted for publication in Nuclear Instruments and Methods.

A practical guide for the evaluation of silicon semiconductor detectors for fission fragment energy measurements is given. The evaluation is based on shape parameters associated with the pulse amplitude spectrum for ^{252}Cf spontaneous fission fragments. Reasonable limits for these parameters are suggested and the significance of each is discussed. Measurements of similar parameters for the ^{235}U thermal-neutron fission fragment pulse amplitude spectrum are reported. A method for computer determination of the spectrum parameters is included.

26. Elastic and Inelastic Scattering of Protons from ^{107}Ag and ^{112}Cd -- J. L. C. Ford, Jr., P. H. Stelson, and R. L. Robinson

Angular distributions for the elastic and inelastic scattering of 13 MeV protons from ^{107}Ag and ^{112}Cd have been measured between the angles of 22.5° and 165°. The proton groups were detected with a surface barrier detector with a resolution of about 30-40 keV.

In the case of ^{107}Ag angular distributions for nine excited states have been measured. Assuming ^{107}Ag can be described by the weak particle core coupling model, the required number of states are observed in the energy region corresponding to the first 2+ and two phonon states of ^{106}Pd. Further, the angular distributions for the .324 keV and .423 keV excited states of ^{107}Ag are well fitted by the angular distribution for the first 2+ state of ^{106}Pd. However, only one strong state is observed in ^{107}Ag in the energy region corresponding to the 3- state in ^{106}Pd.

In the ^{112}Cd energy spectra 5 states are observed in the two-phonon energy region, as well as the groups corresponding to the ground state, first 2+ state and collective 3- state.

These data are being fitted using the distorted wave Born approximations, and the coupled equations approximation.

27. Coulomb Excitation of States in the Chromium Nuclei -- F. K. McGowan, P. H. Stelson, R. L. Robinson, W. T. Milner, and J. L. C. Ford, Jr.

The following is an abstract of a paper to be presented at APS Topical Conference, Gatlinburg, Tennessee, November 11-13, 1965.

Helium-4 and ^{16}O ions with energies of 4 to 5.6 MeV and 30 to 39 MeV, respectively, have been used to Coulomb excite states in the nuclei $^{50,52,53,54}Cr$. The excitation functions for the 565-, 1010-, and 1290-keV γ rays from ^{53}Cr establish that these transitions result from direct E2 excitation of states at these energies. The angular distribution of the γ rays with respect to the incident ion beam are consistent with an assignment of 1/2(E2-M1)3/2, 5/2(E2-M1)3/2 with $(E2/M1)^{1/2} = 0.43 \pm 0.08$, and 7/2(E2)3/2 for the 565-, 1010-, and 1290-keV transitions, respectively. In addition to the first 2+ states in $^{50,52,54}Cr$, states at 1878 ± 10- and 1828 ± 10-keV are also excited in ^{50}Cr and ^{54}Cr, respectively. If these states are interpreted to be the result of double E2 excitation of a 4+ state, the values obtained for the ratio $B(E2, 4 \rightarrow 2)/B(E2, 2 \rightarrow 0)$ are 1.80 ± 0.29 and 2.16 ± 0.35. Data (see for instance K. Way et al., Nuclear Data Sheets) from radioactive decay and the nuclear reactions (n,γ) and (d,p) favor the 4+ assignment. A 0+ assignment seems quite unlikely because the data yield $B(E2, 0' \rightarrow 2)/B(E2, 2 \rightarrow 0) = 13$.

28. Analysis of Elastic and Inelastic Scattering of Neutrons from ^{206}Pb, ^{208}Pb, and ^{209}Bi Below 4.5 MeV -- W. R. Smith

The following is the abstract of an ORNL Report (ORNL-TM-1238) in preparation.

The Hauser-Feshbach compound nucleus scattering theory has been applied to neutron elastic and inelastic scattering from ^{206}Pb, ^{208}Pb, and ^{209}Bi in the energy range 0.8 to 4.5 MeV. The theory appears to work quite well for both the compound-elastic scattering and the inelastic scattering, provided that the imaginary potential W has the correct energy dependence. The results show that for the isotopes considered W should be constant as a function of bombarding-minus-excitation energy and nearly constant as a function of bombarding energy above 4 MeV bombarding energy, but should be made increasingly smaller as the bombarding energy is lowered below this amount.

29. Studies of Resonance Parameters of ^{239}Pu -- J. Blons (CEN, Saclay), H. Derrien (CEN, Saclay), A. Michaudon (CEN, Saclay), P. Ribon (CEN, Saclay), and G. deSaussure

The following is an abstract of a paper presented at the International Conference on the Study of Nuclear Structure with Neutrons, Antwerp, Belgium, July 19-23, 1965.

The resonance parameters of ^{239}Pu were determined from total cross-section measurements up to 200 eV and from previously reported measurements of fission cross sections. The experimental techniques and method of analysis of the results are briefly described, and the resonance parameters are given. It seems that up to 200 eV few resonances are missed, though there is some ambiguity (asymmetry explicable either by interference or by small resonances). A statistical study is made on level spacings, and reduced neutron-, radiation-, and fission-width distributions. Several resonances have very great width ($\Gamma > 1$ eV); the radiation widths Γ_γ fluctuate quite strongly and are not consistent with a constant value; the fluctuations are comparable with the ones observed for ^{235}U.

30. Secondary Gamma Rays from Proton Bombardment of Different Materials -- G. T. Chapman, F. C. Maienschein, J. H. Todd, and W. Zobel

The measurements of the production cross section for secondary gamma rays which were previously reported (W. Zobel, F. C. Maienschein, and R. J. Scroggs, Spectra of Gamma Rays Produced by the Interaction of ~ 160-MeV protons with Be, C, O, Al, Co, and Bi, ORNL-3506 (April 1965)) have now been extended to include other materials, lower incident proton energies, and incident alpha particles.

The equipment used for this set of experiments is essentially the same as that used before. Time-of-flight discrimination against the secondary neutrons produced during the bombardment proved to be impractical, so that the contribution from neutrons was determined in each case by closing the spectrometer collimator with lead and/or iron, and measuring the spectrum.

The Oak Ridge Isochronous Cyclotron (ORIC) was the source of the bombarding particles. Protons with about 56 MeV, 33 MeV, and 16 MeV, and alphas with 58 MeV incident energy were used in these runs. The energy of the incident particles was measured by determining the range of the particles in aluminum absorbers.*

The majority of the measurements were made with the spectrometer axis at 135° to the incident beam. In order to ascertain possible anisotropies in the angular distribution, some spectra (notably carbon) were also taken with the spectrometer at other angles to the beam. The following table summarizes the experimental conditions.

The analysis of the data is currently in progress. The method is the same as reported previously (W. Zobel, F. C. Maienschein, and R. J. Scroggs, Spectra of Gamma Rays Produced by the Interaction of ~ 160-MeV Protons with Be, C, O, Al, Co, and Bi, ORNL-3506 (April 1965)). Since

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*The authors are indebted to R. T. Santoro and F. E. Bertrand for the measurements of the particle energies.

the data taken with the total absorption spectrometer now extend to about 9 MeV, as compared with about 2.5 MeV in the runs made at Harvard, the response functions had to be extended to cover this range. Some difficulties were encountered in the process, mostly due to the required inclusion of escape peaks.

Preliminary results from the analysis of the data teken with the spectrometer in the pair mode are shown for the case of carbon at 135° in Fig. 2. It is clear that the cross section for production of the 4.4 MeV gamma ray, for example, increases greatly with decreasing energy of the incident proton.

	16 MeV p	33 MeV p	56 MeV p	58 MeV α
^{7}Li		135°		
Be	135°,90°	135°	135°	135°
^{11}B		135°	135°	
C	135°,90° 50°	135°,90° 60°	135-,90°	135°,90° 51.5°
O (BeO)	135°,90°			135°
O (H_2O)		135°	135°	
Mg		135°		
Al	135°,90° 50°	135°	135°	135°
Fe	90°	135°		135°

31. Differential Neutron Cross Sections for Several Materials Bombarded by 14-, 18-, and 56-MeV Protons -- M. Young (Research participant from Louisiana State University), V. V. Verbinski, J. C. Courtney (Catholic University, Washington, D.C.; ORINS Graduate Fellow), and W. R. Burrus

Differential "net" (p,n) cross sections have been determined as a function of neutron energy and neutron emission angle for several materials bombarded by 14-, 18-, and 56-MeV proton beams. Targets which removed about 10 MeV from the incident beam of Be, ^{11}B, C, O, and Al, were bombarded by 56-MeV protons. Measurements were made at an emission angle of 64° for all these elements and at 30° for Be alone. Targets which removed about 1 MeV from the incident beam were bombarded by 14- and 18-MeV protons, the measurements covering emission angles of from 0 to 170°. At 18 MeV

the targets were Be, N, Al, Fe, In, Ta, and ^{208}Pb, and at 14 MeV they were Be and ^{208}Pb. The resulting net cross section is defined by

$$\sigma(p,n)_{net} = \sigma(p,n) + \sigma(p,pn) + 2\sigma(p,2n) + \ldots$$

The final differential (p,n) cross sections will be determined from the thickness of the targets, the integrated proton current, and the absolute neutron spectrum. The absolute spectrum from about 0.5 MeV to the maximum neutron energy is being unfolded by means of the FERDO general-purpose unfolding code from pulse-height distributions measured with a calibrated NE-213 liquid organic scintillator. The cross section results will be presented in the laboratory system in terms of barns steradian^{-1} MeV^{-1} as a function of emission angle and neutron energy for each bombarding energy. A transformation to the center-of-mass system cannot be made because the different reaction mechanisms leading to neutrons were not separated.

The following abstracts were presented at the American Physical Society Meeting, Washington, D.C., April 26-29, 1965

1. Cross Section Measurements for Nucleon and α-Particle Transfer Reactions Induced by ^{14}N Ions -- I. R. Williams, R. M. Gaedke (ORINS Graduate Fellow), and K. S. Toth.

2. Angular Distribution of ^{18}F Particles from the Reaction $^{16}O(^{14}N,^{18}F)^{12}C$ -- R. M. Gaedke (ORINS Graduate Fellow) and K. S. Toth.

3. Magnetic Moment of the 77.3 keV First Excited State of ^{197}Au -- Dietrich Seyboth (on leave from the University of Erlangen, Germany), F. E. Obenshain, L. D. Roberts, and J. O. Thomson (University of Tennessee).

4. (p,α) Reaction on ^{90}Zr at 20.2 MeV -- C. B. Fulmer and J. B. Ball.

5. Energy Levels of ^{86}Sr and ^{87}Y Studied with ^{89}Y and $^{90}Zr(p,\alpha)$ Reactions -- J. B. Ball and C. B. Fulmer.

6. Response of Ge and Si Detectors to Energetic Br and I Ions -- W. W. Walker (Summer research participant from University of Alabama), C. D. Moak, and J. W. T. Dabbs.

The following abstract was presented at the American Physical Society Meeting, New York, June 23-25, 1965.

1. $^{12}C(d,^{6}Li)^{8}Be$ and $^{12}C(d,^{7}Li)^{7}Be$ at 34.2 MeV -- R. S. Bender and E. Newman.

FIGURE CAPTIONS

Fig. 1 - Neutron Time-of-Flight Spectra of Capture and Fission Events in the ^{235}U Chamber. (ORNL-DWG-65-4628).

Fig. 2 - Cross Section for the Production of Gamma Rays by Protons Incident on a Carbon Target. Gamma rays emitted at an angle of 135 deg. from the proton beam. (Dwg. 2-01-058-1003).

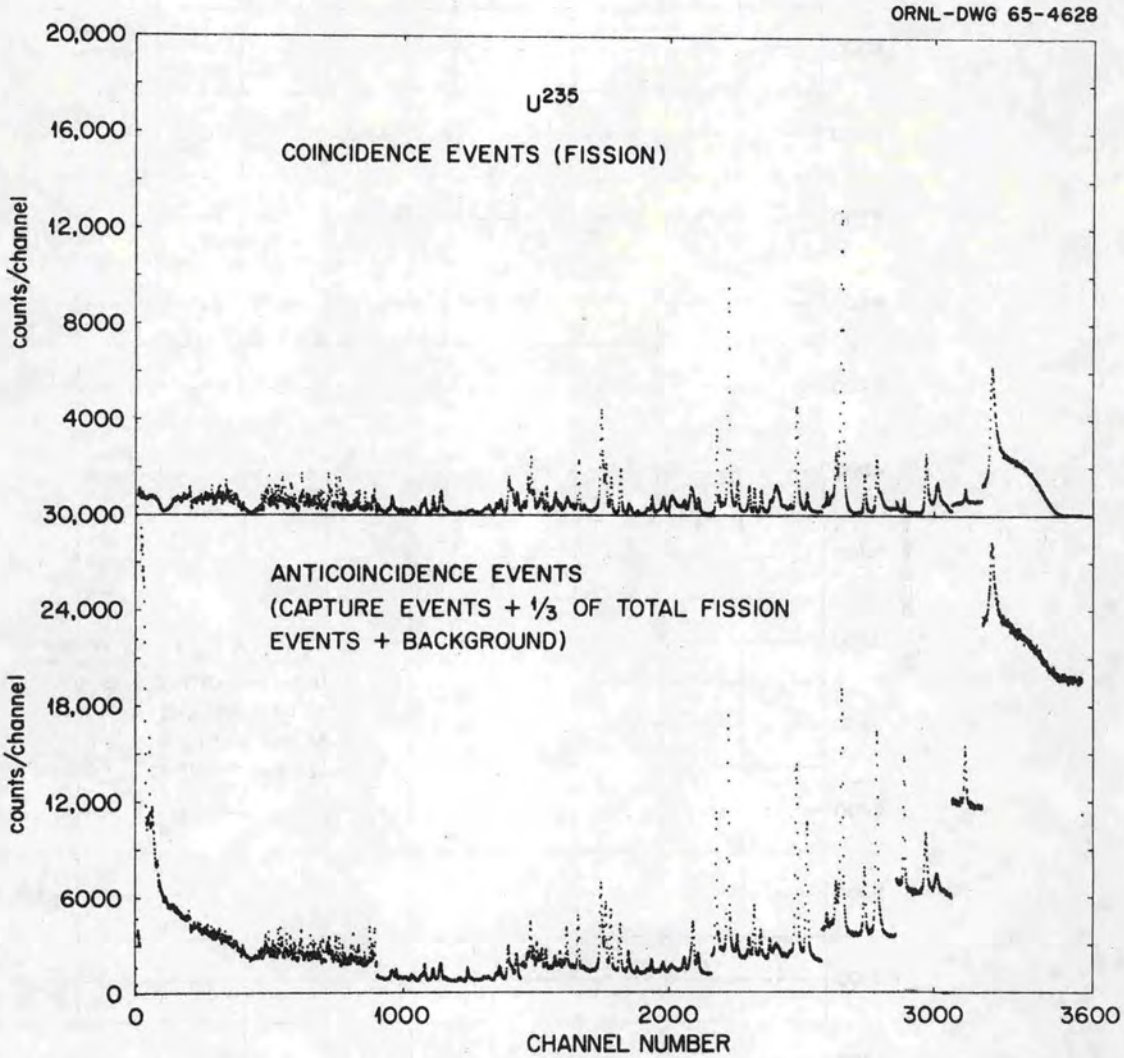
ORNL-DWG 65-4628
U235
COINCIDENCE EVENTS (FISSION)
ANTICOINCIDENCE EVENTS
(CAPTURE EVENTS + 1/3 OF TOTAL FISSION
EVENTS + BACKGROUND)
counts/channel
20,000
16,000
12,000
8000
4000
30,000
24,000
18,000
12,000
6000
0
0
1000
2000
3000
3600
CHANNEL NUMBER

Fig. 1

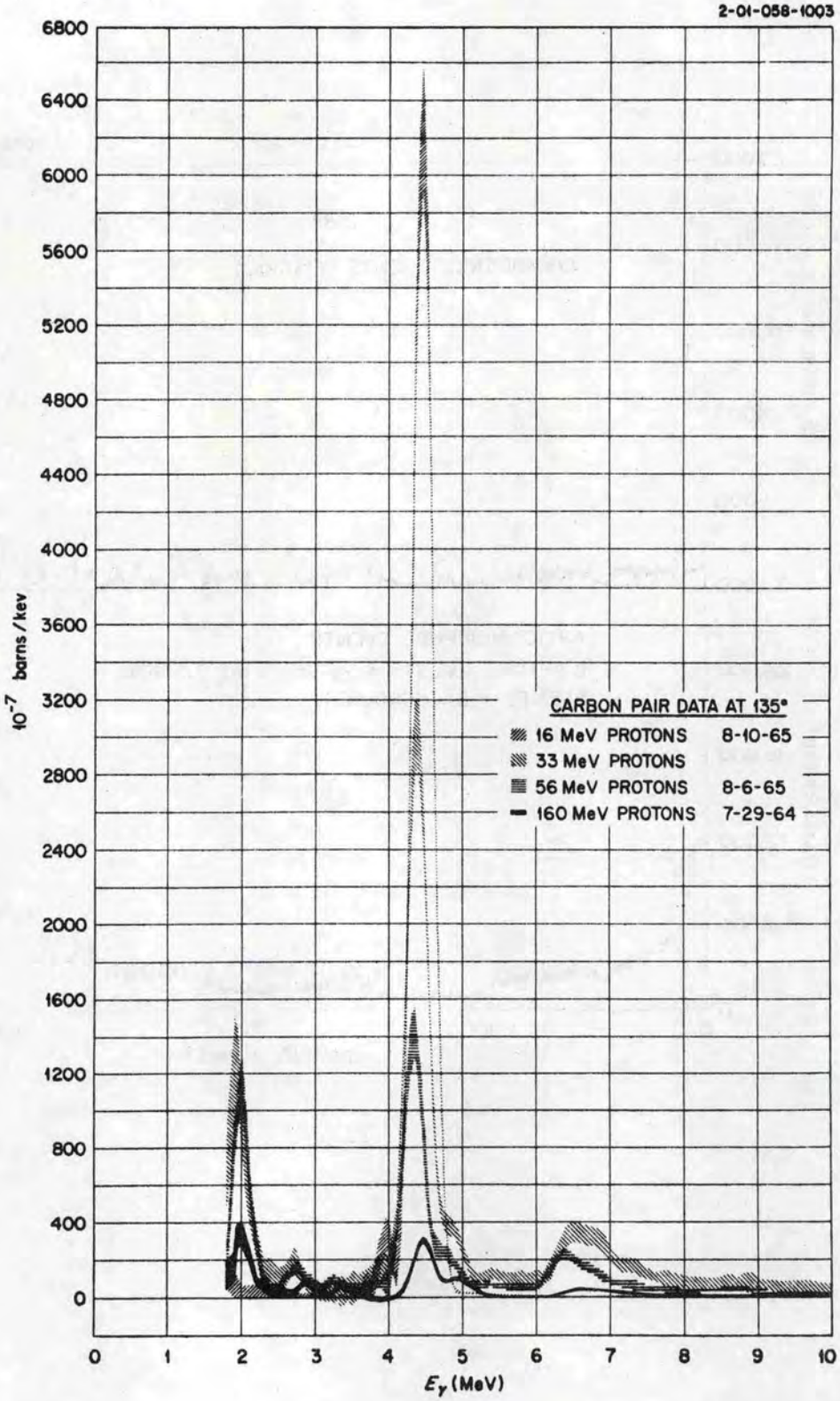
2-01-058-1003
6800
6400
6000
5600
5200
4800
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
10^{-7} barns / kev
CARBON PAIR DATA AT 135°
16 MeV PROTONS 8-10-65
33 MeV PROTONS
56 MeV PROTONS 8-6-65
160 MeV PROTONS 7-29-64
0
1
2
3
4
5
6
7
8
9
10
E_γ (MeV)

Fig. 2

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